Transforming our World Through Design, Diversity and Education
G. Craddock et al. (Eds.)

doi:10.3233/978-1-61499-923-2-832

Should Colour Vision Deficiency Be a Recognized Special Education Need (SEN)?

Anne Kristin KVITLE[a,1]
[a] *Department of Manufacturing and Civil Engineering, NTNU Norwegian University of Science and Technology*

Abstract. A colour vision deficiency (CVD) is a condition that affects about one in 12 of the male population, and one in 200 of the females. On average, there is at least one student in every classroom affected by a reduced colour vision. In schools and in teaching, colours are used as a tool to identify, group, highlight, warn and explain. For a colour vision deficient student, the colours used to code the information may be a source of confusion instead of a tool to decode. This paper provides an overview of the possible academic and social-emotional challenges for CVD students and propose strategies and actions to raise awareness and enable colour universal design.

Keywords. Colour vision deficiency, learning, SEN, colour universal design

Introduction

Colour vision deficiencies (CVD) are common, with about five percent affected in Caucasian societies. The condition is linked to gender, and eight percent of males and 0.4 percent of females have a reduced colour vision. The condition is caused by a missing cone (dichromacy) or dysfunctional cone (anomalous trichromacy), where the CVD is categorized by the affected cone (protan, deutan or tritan) [1][2][3]. The term "colourblind" is common, but misleading. The affected individuals (except for the rare condition of monochromacy) are able to see colours, but their perceived gamut is limited and their ability to discriminate colours is reduced.

A person with a CVD is able to see colours, but may have problems to distinguish and identify the colours that people with normal colour vision consider as different colours. Simulations are often used to give people with normal colour vision an impression on how colours may appear for a CVD observer. A collection of colour pencils will look very different to a person with a CVD. This is illustrated in Figure 1, where the pencils appear to be a rainbow palette for normal colour vision (left) while the deuteranope simulation (right) appear as a collection of green, yellow and blue. This simulation was created in Adobe Photoshop using ICC profiles [4]. Several simulation methods exist, and can be implemented in different ways such as plug-ins in browsers or software, or as standalone tools.

[1] Corresponding Author, The Norwegian Research Laboratory for Universal Design, NTNU Gjøvik, Teknologivegen 22, 2815 Gjøvik, Norway; E-mail: anne.kvitle@ntnu.no..

Figure 1. Colour pencils with normal colour vision (left) and CVD simulation of deuteranopia (right) [5].

Simulations can be good tools to illustrate or discover problematic colour combinations, but do not substitute the real subjects in assessing to what extent colour coded information is colour universal designed or not. First, they are based on theoretic model(s) of colour vision and may not be representative for real observers [6]. Second, there may be large individual differences between observers even with the same CVD type [7][8] and third, the simulations target specific types of CVD and specific applications such as natural images or information graphics [9] and may not be applicable to other image types.

As colour is often used as an aid for problem solving or code in a task, a person with a CVD will often misinterpret the task or code, and not be able to solve the task as intended. This will often lead to a situation of failure for the student, or in the worst cases a suspicion of a classification within the spectrum of learning difficulties like dyslexia.

As colour vision testing has been phased out of the common vision screening or health examinations for children, there is a large probability of undiagnosed CVD among children in school. The challenge of having a CVD is described within several disciplines of science, from visual science to psychology. The possible risk of facing difficulties in learning and social activities at school are leading to a discussion of which CVD should be considered as a special education need (SEN) and a disability.

This paper provides an overview of the possible challenging situations for students with CVD. These challenges are based on existing literature and personal stories from subjects participating in studies at the NTNU and the Universal Design Laboratory. The challenges can be addressed on two areas; academic and social and emotional life. Finally, strategies and actions to raise awareness and enable colour universal design are suggested.

1. The challenges of a CVD student

May the reduced ability to discriminate colours be considered as a learning disability? This was debated in 1973 in the paper "Color Vision Deficiency: A Learning Disability?" [10], where the hypothesis was that CVD could be associated with impaired learning and inappropriate classroom behavior. Here, the author raised the following important question: "Did the color vision deficient child's early "failures" in performing some of his school related tasks have potentially long-range ramifications in terms of school achievement and behavior development?". This was later addressed in the literature review of Wilkinson [11], studying the cognitive and social-emotional correlates of colour deficiency in children, where the review revealed that too little research is done in this field of interest and that the existing research is inconclusive. In a comprehensive

review [12], the impact CVD may have on an individual's life is described from play age to late adulthood with respect to the psychological and social aspect as well as possible learning difficulties. A summary of challenging activities is illustrated in Figure 2, republished with the permission of the authors [12].

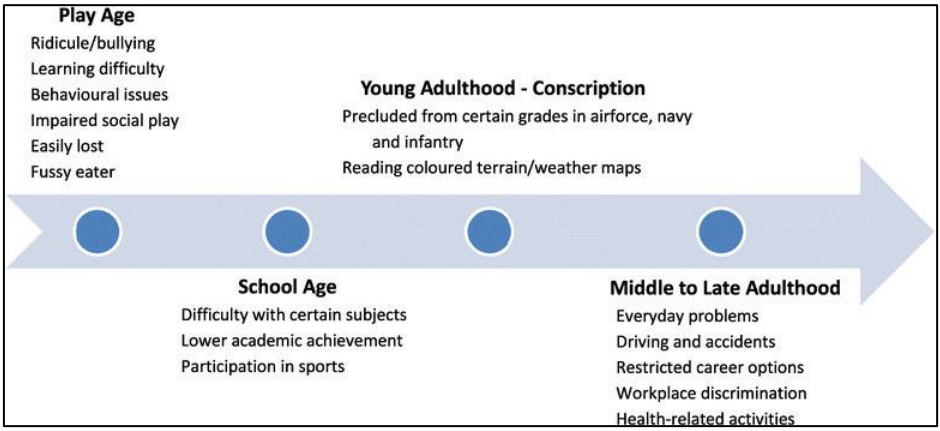

Figure 2. Summary of activities that can be affected by CVD across various stages of life [12], reproduced with the courtesy of the authors.

This summary illustrates how misunderstanding colour coding and misinterpret information can affect the childs life at an early age. Picking berries is among the activities observers from the author's study recall as a challenging and even unpleasant activity. This task was difficult as they had problems to detect the berries and the ripeness and consequently they were slower than the other children to fill their bucket with berries. Finding coloured objects, such as a red ball in the green grass, could be impossible. Participating in sport and other activities where recognizing the colours of your teammates' sport kit colours is difficult, and the attractiveness of popular leisure games like laser tag is lost when it is impossible to see the laser beams or the red or green targets.

There is no doubt that most people with a reduced colour vision experience problems with colours in everyday life [13] and the problem is increasing as colour is used in printed materials, computer displays and smartboards in classrooms. In Cole's review of studies, up to sixty percent of the users with abnormal colour vision reported problems in observational task as reading colour coded charts, slides and prints. Advances in technology may ironically enough make daily life of CVD observers harder than ever before as the advent of inexpensive colour printing and the universal adoption of colour computer monitors enable colour to be more widely used for coding information and organizing complex visual displays [13][14]. Observers with a CVD now encounter coloured stimuli much more often than in the past. In the classrooms, the traditional blackboard could be challenging when a red colour was used to emphasize. Nowadays this blackboard is replaced by a Smartboard which gives even more possibilities to use colours to code information that may be misinterpreted by a child with CVD.

Colour vision is not tested as often as it should be [15], as twenty to 30 percent of adults with reduced colour vision are not aware of their condition. Further, sixty percent of the anomalous trichromats and thirty percent of the dichromats reported that they were unaware of their condition while they were at school [16]. In 1958, the Ishihara test was adopted the method for assessment when colour vision testing was required as part of the School Health Act in Japan, a practice that was common in several countries around the

world. Unfortunately, this practice is no longer part of the vision screening or medical examination for (preschool) children in many countries. For this reason, school children with a CVD may go undiagnosed through their education.

The challenges described for learning and everyday life, can be can be identified as challenges in academic life and social-emotional life.

1.1. Academic life

In schools and in teaching, colours are used as a tool to identify, group, highlight, warn and explain. A student with CVD will not be able to see the cues to decode the information given, and is literally lost when colour is the only key to decode information. Figure 3 illustrates an example of how colours are used in mathematics to train skills in fractions. For a student with CVD, it is difficult to see the difference between the red, green and blue balls. Coloured objects are common in disciplines where the task is to identify and classify, and frustration is high for these students when the colours used as identifier are not distinguishable.

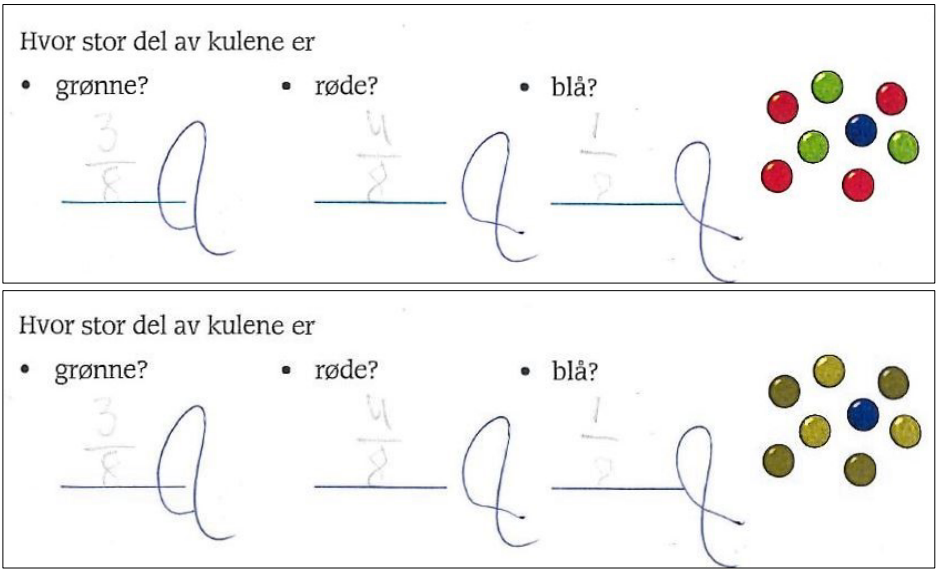

Figure 3. Example of how to learn fractions from textbook in fifth grade where the student is asked to count how many green, red and blue balls. Original (top) and CVD simulation (bottom).

The review [12] provides a summary of common difficulties in specific subjects, which have been addressed in several disciplines [17][18][19][20][21]. This summary is listed in table 1, including data from the author.

Table 1. Common difficulties faced by CVD students in academic subjects, reproduced with courtesy of the authors [12] and expanded with the authors data.

Subject	Area of difficulties
Art	Unable to appreciate how colours are used.
	Use of wrong colours when painting or colouring.
Chemistry	Unable to read litmus paper accurately.
	Unable to tell the colours of different chemical solutions in quantitative analysis.
	May be unable to identify metals by colour of flame produced when metal is burnt.
Biology	Unable to accurately read stained slides under microscope
	May not be able to identify species of plants.
	May not be able to accurately carry our dissections.
	May have difficulty understanding coloured diagrams in textbooks.
Physics	Will have difficulties with coloured wires and use of prism.
Maths	Unable to read pie charts and graphs.
Geography	Difficulties or unable to read and decode maps.
	Unable to reproduce maps.
Physical education	Unable to distinguish teammate and opponents.
	Unable to recognize targets or objects.

As summarized in the table, a CVD may be a challenge in most academic subjects.

1.2. Social and emotional life

A child with CVD be slower at colour coded tasks and will make more errors. Being unaware of their condition, the child is at risk of developing low self-esteem because of a series of failures. When an elderly man learned he had a CVD at the age of 80, he was relieved of this because he had always though "he was not bright enough to have learned his colours properly when he was at school" [16]. Further, the action of a child doing the opposite of what he or she is told may be misinterpreted as misbehavior. If the child is told to go to the red group and goes to the green instead, it is because the child is not able to see the difference between the red and green group.

2. What can be done?

To help the CVD students to overcome their challenges in school, awareness of what CVD is and how to increase accessibility is required.

2.1. Awareness

Studies show that CVD is underdiagnosed, so many children and their parents are not aware of the situation and the possible difficulties and challenges the child might face. Further, caretakers and teachers should be aware of what CVD is, and how CVD affects the child. Pre-school colour vision testing should reintroduced as a part of the common vision screening or health examinations for children. As colour is used as an aid and tool in teaching, it is therefore important that the child, parents and teacher are aware of the condition to take precautions.

In the United Kingdom, the Community Interest Company "Colour Blind Awareness"[2] have worked to raise awareness for the need of colour vision testing for children and for CVD to be recognize as a special education need [22].

2.2. Colour universal design

Colours should never be the only cue to decode information, and some principles for colour universal design and recommandations [14, 20] include

- Choose colour schemes that can be identified
- Combine colour with shapes, positions, patterns etc.
- Use labels in addition to colours

As the colour appearance is affected by the actual lighting conditions and usage environment, these conditions should be taken into account when designing for the learning situation.

The demand for universal design is more becoming part of standards, initiatives, acts and laws such as the Section 504 and 508 of the "Rehabilitation Act of 1973" (US), "Disability and Discrimination Act" (UK) and the "Lov om forbud mot diskriminering på grunn av nedsatt funksjonsevne" (Norway). In such initiatives, CVD is often recognized as a disability. However, CVD is not yet recognized or understood as a learning difficulty.

3. Discussion and conclusion

Several sources in the literature review point out the necessity of colour vision testing of (pre-) school children, a practice that was common previously. A diagnosed CVD will aid both awareness and understanding of the condition for all involved: not only for the child and the teacher, but possibly also the classmates and parents. An undiagnosed CVD will not only put the educational success at risk, but is a potential source of "failures" in tasks that demands decoding information based on colour codes which may be confused with other special education needs.

As colour is used as a didactic tool, it is essential to be aware of how a reduced colour vision affects the ability to discriminate colours. Despite the large number of people affected by a CVD, the condition and how it affects the ability to discriminate colours is not commonly known. For this reason, there is a need to educate teachers in how to make teaching material accessible for CVD students and to demand the textbook publishers to verify that the textbooks are accessible for CVD students.

Recognizing CVD as a learning challenge that requires special education need is a first step towards an accessible learning situation for these children

[2] www.colourblindawareness.org

References

[1] J. Birch, Worldwide prevalence of red-green color deficiency, *Journal of the Optical Society of America A* **29** (2012), 313-320.

[2] B. Cole, Assessment of inherited colour vision defects in clinical practice, *Clinical & Experimental Ophthalmology* **90** (2007), 157-175.

[3] S. J. Dain, Clinical colour vision tests, *Clinical & Experimental Ophthalmology* **87** (2004), 276-293.

[4] P. Green, P. Nussbaum, Colour vision deficiency transforms using ICC profiles, *IS&T International Symposium on Electronic Imaging, Color Imaging XXI: Displaying, Processing, Hardcopy, and Applications*, 2016 pp. 1-5

[5] A.K. Røise, A.K. Kvitle, P. Green, Colour coding of maps for colour deficient observers, poster at the 3rd International Conference on Universal Design (UD 2016), York, United Kingdom, August 21 – 24, 2016

[6] P. Green, "Why simulations of colour for CVD observers might not be what they seem," in *Color Imaging XX: Displaying, Processing, Hardcopy, and Applications*, 2015.

[7] D.R. Flatla, C. Gutwin, Individual models of color differentiation to improve interpretability of information visualization, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Atlanta, Georgia, USA. (2010).

[8] D.R. Flatla, C. Gutwin "So that's what you see": building understanding with personalized simulations of colour vision deficiency. *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility*, Boulder, Colorado, USA. ,(2012).

[9] J.T. Simon-Liedtke, I. Farup, Using a Behavioral Match-to-Sample Method to Evaluate Color Vision Deficiency Simulation Methods, *Journal of Imaging Science and Technology* **60** (2016) .

[10] S.D. Espinda, Color Vision Deficiency: A Learning Disability? *Journal of Learning Disabilities* **6(3)** (1973), 163-166.

[11] W.K. Wilkinson, The Cognitive and Social-Emotional Correlates of Color Deficiency in Children: A Literature Review and Analysis, *Adolescence* **27** (1992), 603-611.

[12] X.B.V. Chan, S.M.S. Goh, N.C. Tan, Subjects with colour vision deficiency in the community: what do primary care physicians need to know?, *Asia Pacific Family Medicine* **13** (2014).

[13] B.L. Cole, The handicap of abnormal colour vision, *Clinical and Experimental Optometry* **87(4-5)** (2004), 258-275

[14] Color Universal Design Handbook, EIZO, in [https://www.eizoglobal.com/products/coloredge/unicolor_pro/handbook.pdf].

[15] J.M. Steward, B.L. Cole, What do colour vision defectives say about everyday tasks? *Optometry and Vision Science* **66** (1989), 288-295.

[16] B.L. Cole, Assesment of inherited colour vision defects in clinical practice, *Clinical and Experimental Optometry* **90** (2007), 157-175.

[17] About Color Blindness (Color Vision Deficiency): Life's minor frustrations (and occasional dangers) for the color blind. In [http://www.toledo-bend.com/colorblind/aboutCB.asp].

[18] Testing Color Vision: Frequently Asked Questions. In [http://colorvisiontesting.com/color7.htm].

[19] K. Sullivan , The colour conundrum. In SecEd, Volume 15; 2011.

[20] K. Albany-Ward, Why colour really does matter. In Prep School, **15** (2011), 36–37.

[21] J.A.B Spalding: Doctors with inherited colour vision deficiency: their difficulties in clinical work. *In Colour Vision Deficiencies XIII,* 1997:483–489.

[22] K. Albany-Ward, M. Sobande. What do you really know about colour blindness? *British Journal of School Nursing*, **10** (2015), 197-199.